

## Drainage network development in the Pannonian Basin

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### Abstract

The evolution and development of the greatest rivers in the Pannonian Basin have been investigated for almost 150 years. At the end of the Late Miocene Sub-Epoch (7.5–5.3 Ma BP) and at the beginning of Pliocene Epoch (5.3–4.5 Ma BP) Lake Pannon shrank dramatically, filled up with sediments and completely dried up as a result of global climate change (Bérbaltavarian /Messinian/ Stage). In the basin dominated by dry climate conditions, torrents bordered with riparian forests appeared. During the Lower Pannonian Stage (Eppelsheimium in the Hungarian terminology) the tropic rainforests which previously had covered even regions at higher latitudes contracted to a smaller area around the Equator due to the global climate change. Then under the warm and humid climate of the Middle and Late Pliocene (Csarnotian and Ruscinian Stages, 4–3 Ma BP) tropic rainforests expanded again and the drainage network development of the Pannonian Basin continuing even today started. During our research, climate-indicating travertine layers covering the terraces, travertine stratigraphy and fauna findings were investigated.

**Keywords:** travertine stratigraphy, plate movements, global climate change, fluvial and abrasive terraces, pediments, evolution of River Danube

### River and history

According to the archives, the word *Danube* was already known as early as in the 7<sup>th</sup> century BC. The Greek called its lower river section situated between the Iron Gates and the Black Sea *Ister*. After occupying Illyria in 168 BC, the Romans called the river *Danubius* and they established that *Ister* and *Danubius* were the same river. Julius Caesar used the name *Danube* for the first time. The river was worshipped as a deity during the Roman Empire (KÁDÁR, L. 1980). The word *Danube* is of Celtic origin and it means “water”, “river”. It was transmitted into the Hungarian language by the northern Slavic nations. Its foreign versions (*Danube*, *Donau*, *Danubio*, *Dunaj*, *Dunarea*, *Dunav*, etc.) are of ancient origin as well.

The headspring of the river *Danube* has not been known for so long as it would be expected. Herodotus (484–408 BC) believed that the source of the *Danube* was in the Pyrenees. During the Second Punic War (218–201 BC) the Romans realized while they were crossing the lower section of *Rhone* that Herodotus had been wrong. Later, they suspected that the *Danube* originated in the mountains of *Bretagne* away from the Pyrenees. However, that presumption was proved to be mistaken, too. The false assumption was clarified during the Gallic Wars (58–51 BC) waged by the Roman proconsul Julius Caesar who, however, did not manage to find the spring of the *Danube* and assumed that the river originated in the Southern Alps. In the end, the source of the river, namely the Black Forest was discovered only in 14–16 AD.

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The Danube has been involved in several significant events of world history, just to mention some of them: Attila the Hun, the leader of the Hunnic Empire rushed along the Danube (406–453 AD) as far as the Catalaunian Plains to fight with the Western world. Charlemagne and his troops also marched along the river to put down the reign of the Avars. The Danube is the second longest river in Europe (after the Volga). The total length of the river is 2,860 km, including the Hungarian section as long as 417 km. The 140-km-long river section between Oroszvár and the Ipoly estuary (Szob) marks the border between Hungary and Slovakia. The Danube reaches Hungary as a large river.

### **The Hungarian section of the Danube**

As a result of river regulations, the Hungarian section of the Danube is not entirely navigable. The river regulations carried out at the end of the 19<sup>th</sup> century and at the beginning of the 20<sup>th</sup> century converted the natural river into an artificial channel.

The Danube enters the Little Hungarian Plain at the meeting point of the Alps and the White Carpathians at 130 m a.s.l. After flowing through the so called “Porta Hungarica” at Devin (today a district of Bratislava), the Danube reaches the Little Hungarian Plain transporting an immense amount of alluvial sediments (pebbles, sand, silt). The sediment transport mainly results from floods, the frequency of which has decreased significantly since the construction of the Austrian and Slovakian dams (Gabčíkovo Dams).

The largest European island can be found in the Little Hungarian Plain. It is called “Golden Garden”, involving the Szigetköz as the Hungarian part and the Zitny Ostrov (in Hungarian ‘Csallóköz’), as the Slovakian part of the alluvial fan. The vicinity of the two regions is an endless plain, the surface of which is built up of point bars. The Danube flows on the top of the alluvial fan where the main channel had changed its direction

quite frequently before the river regulation works. River bar evolution made the Danube meander and change its flow resulting in the development of several alluvial fans. Thus, the Danube had no main channel even at the beginning of the 19<sup>th</sup> century.

The archeological findings confirm that the navigable main channel of the Roman era is equivalent to the contemporary Moson Danube. The region also serves as one of the most significant drinking water supply of the northern part of the Transdanubia and the southern part of Slovakia. The gold of the “Golden Garden” is the drinking water itself. The main responsibility of the authorities and the scientific world is to preserve that treasure. It is a fundamental interest to restore the water balance prior to the construction of the Gabčíkovo Dams to maintain and protect the strategic drinking water supplies. The water regime and the water balance of the Danube are controlled mainly by the precipitation received by the catchment areas of the Austrian Alps and Prealps as well as the melt water of snow and glaciers.

### **Fluvial land-forming processes of the Danube**

The immediate vicinity of the river is formed by river-bed changes. The Hungarian section of the river can be characterized by river down-cutting and valley filling. Upper courses are rare along the Hungarian section of the river. Even the Visegrád Gorge cannot be considered as a pure incising valley type as point bars can be observed in several places. Valley filling is not very frequent either, rather a transient type of cutting and filling. There are river sections where river down-cutting is as frequent as valley filling. In that case erosion and deposition alternate each other. That’s why the valley is neither down cut nor filled with alluvium to a great extent. For example, between Bratislava (Slovakia) and Gönyű (Hungary) filling is the most typical river function, therefore, most of the Danube sediment reaching the country are deposited there. The (relatively fast) fluvial deposition resulted in the development of

anabranches. Between Gönyű and Komárom not only deposition but also transportation can be detected since the bedload is partly transported away.

The huge alluvial fan consists of two types: a younger, low-lying alluvial plain, involving Szigetköz, the Moson Plain and the Hanság Plain with the alluvial plain of River Rába. The older and higher situated deltaic and alluvial plain involves, among others, the Parndorf Plain and the Bana Hill (*Figure 1*).

At the northern edge of the Gerecse Hills, the flood plain of the Danube becomes narrower, at Esztergom it widens again, then in the Visegrád Gorge it is only narrow strips following the river banks. Between Vác and Budapest the floodplain of the river is well-defined with clear boundaries, characterized by embayments of various size. It follows the river, especially the left riverbank as far as the southern boundary of the country with a varying width (15–25 km). In many places, both on the right and left riverbanks, extensive depressions occupy the floodplain (BULLA, B. 1941; ERDÉLYI, M. 1955; PÉCSI, M. 1959; SCHEUER, Gy. and SCHWEITZER, F. 1984). Some examples: the Kalocsa and the Baja Depressions on the left riverbank; the Érd, the Adony, the Paks-Tengelic-Sárköz and the

Mohács Depressions on the right riverbank dissected by landslide-effected high bluffs of 40–50 m height. Lots of islands are attached to the feet of the bluffs which are the remnants of larger landslides eroded by the Danube.

The current Danube is flowing from North to South. According to the geomorphologic investigations and radiometric data, during the last interglacial period which was warm and humid, the direction of flow of the Danube was NW–SE, therefore the river was flowing through the Danube–Tisza Interfluve. The direction of flow followed the series of depressions getting younger and younger southwards. However, the Danube changed its direction over time and started to erode the high bluffs of the right Danube riverbank descending in the direction of the Danube–Tisza Interfluve. The area of high bluffs was as wide as 10–15 km and it stretched as far as the western edge of the current Danube–Tisza Interfluve 80,000–100,000 years ago. The Solt Hill and the Tétel Hill are buttes representing the remnants of the former bluff of Mezőföld (*Figure 2*).

The sand dunes of Illancs being an alluvial fan (172 m a.s.l.) also originate from Mezőföld. The alluvial fan had evolved before the Danube changed its direction of flow.

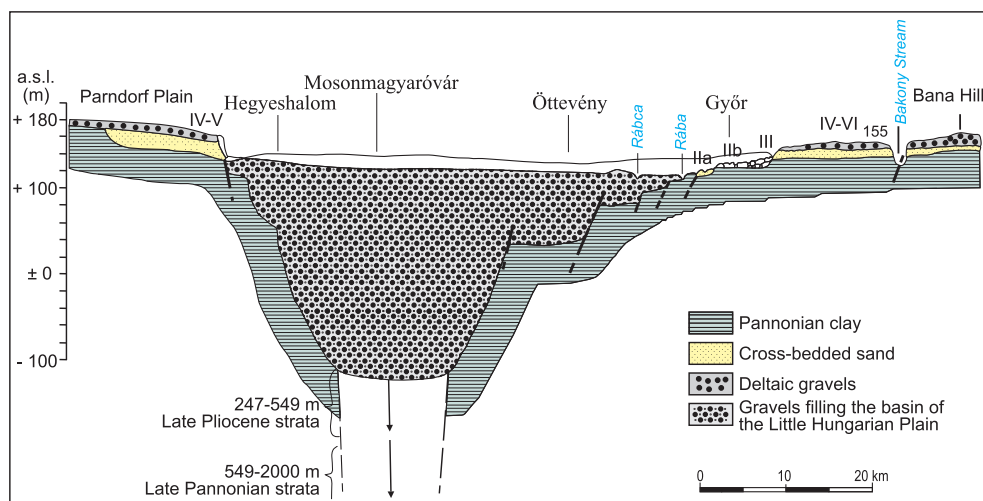


Fig. 1. The area between the Parndorf Plain and the Bana Hill (by Pécsi, M. 1959)

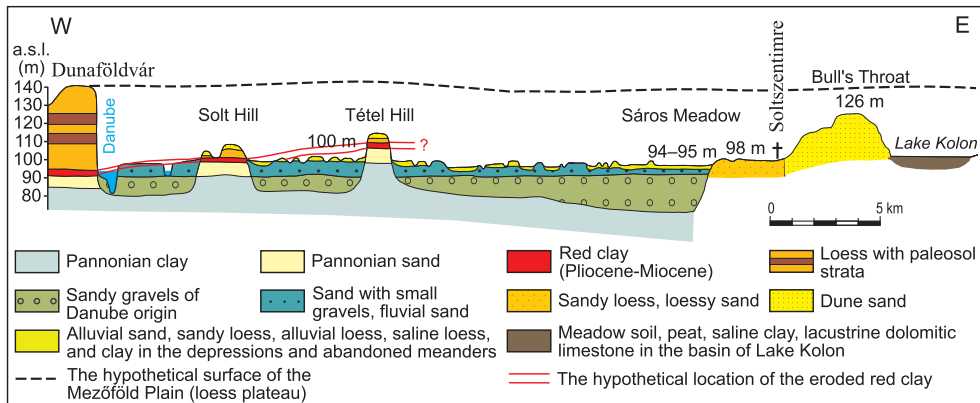


Fig. 2. The terrain and geologic cross-section of the Solt Plain. Based on the data by ERDÉLYI, M. and SÜMEGHY, J. (Ed. by PÉCSI, M. 1959)

### The evolution of the Danube in brief

The evolution of the “ancient” Danube as well as that of the current river have taken a long a time, the duration of which cannot be measured in decades and centuries but in geologic time. So it is not a coincidence that the history of Central Europe’s largest river has been investigated for almost 150 years (SÓBÁNYI, GY. 1893; HALAVÁTS, GY. 1898; CVIJIĆ, J. 1908, 1910; LÓCZY, L. 1913; STRÖMPL, G. 1913; CHOLNOKY, J. 1929; NOSZKY, J. 1933; PRINZ, GY. 1936; SZÁDECZKY-KARDOSS, E. 1939; BULLA, B. 1941; MOTTI, M. 1941; MIHÁLCZ, I. 1953; SÜMEGHY, J. 1953; FINK, J. and MAJDAN, H. 1954; KÁDÁR, L. 1955; KÉZ, A. 1956; PÉCSI, M. 1959; SCHEUER, GY. and SCHWEITZER, F. 1988; GÁBRIS, GY. 2006).

During that period several theories have come into being. The aim has been to locate the gravel deposits situated above 300–330 m a.s.l. and below 100–110 m a.s.l. in time according to the relevant scientific disciplines. Most of the syntheses (PENCK, A. 1894) are in connection with theories on climatically induced fluvial terraces classified by Alpine glacial chronology. Geomorphologists associate the evolution of the fluvial terraces of the Danube with the fluvial system changes related to the last four major Alpine glaciations.

The floodplain is supposed to be of Holocene age, the above lying four gravel-covered terraces are probably of Alpine glacial origin, namely the four Alpine glaciations (KÉZ, A. 1934; BULLA, B. 1941, 1956). It was first investigated by CHOLNOKY, J. (1915), later by KÉZ, A. (1934), KRIVÁN, P. (1953) and PÉCSI, M. (1959).

The difficulties of the issue are well-represented in the fact that due to lack of gravels, Márton PÉCSI could not correlate the terraces located at greater height in the Visegrád Gorge (190–210 m a.s.l. and 240–270 m a.s.l.) (PÉCSI, M. 1959). Several scientists dispute even the Danube origin of the pebbles located mostly at a higher level (VADÁSZ, E. - ex verbis, PÉCSI, M. 1959; LÁNG, S. 1955).

First, it was not easy for scientists to identify the period currently known as Pliocene Epoch between the end of the Pannonian Stage and the beginning of the Pleistocene Epoch extending from 5.3 million to 2.5 million years ago. The existence of the river presently known as the “Danube” during the Pliocene Epoch was not an evidence. On the basis of hypotheses by KÉZ, A. (1934), SZÁDECZKY-KARDOSS, E. (1939), BULLA, B. (1941), KÜPPER, H. (1953), KÁDÁR, L. (1955), PÉCSI, M. (1959), FINK, J. (1961) and THENIUS, E. (1978) associated the development of the

river in the Vienna Basin with the beginning of the Pleistocene Epoch including Early, Middle and Late Pleistocene sub-epochs and extending from Günz till Würm according to the Alpine glacial chronology. The lower boundary of the Pleistocene Epoch was identified as the boundary between the Matuyama and Brunhes Chronozones. Only a few scientists suspected that some of the highest-lying terraces covered with gravels could be older and might have developed during the Late Pliocene Epoch, however, their development was not explained by climate change but plate tectonics (BULLA, B. 1941, 1956; PÉCSI, M. 1959).

In the 1930's and 1940's defining the boundary between the Pliocene and the Pleistocene Epochs was a controversial issue. Some scientists suggested that the so called Upper Levantine strata should be reclassified as Lower Pleistocene strata therefore the incision of the Danube at Visegrád could be classified as an Upper Pliocene event. According to the current nomenclature, the Pliocene Epoch started 5.3 million years ago when the Strait of Gibraltar opened. At that time the vast ice sheet which had developed around the South Pole during a glacial period prior to the quaternary glaciation started to melt which resulted in global sea level rise and the opening of the Strait of Gibraltar (HAQ, B.U. *et al.* 1987; SCHWEITZER, F. 2004) (Figure 3). That geological event took place under a warm and humid subtropical climate during the Csarnotian and Ruscinian Stages (4.3–4 Ma BP) (Figure 4).

Owing to the significant amount of precipitation, the fluvial erosion became dominant in the Carpathian Basin. Besides weathering, red clay deposition, valley formation, the dissection of pediments and landslides were typical. The karst systems were filled up with water, the karst groundwater levels rose which resulted in the resurgence of karst springs depositing travertine at the base level. According to PÉCSI, M. (1980), the oldest Danube terraces located at 230–240 m a.s.l., 280–300 m a.s.l. and 300–330 m a.s.l. were formed during the mentioned period (terraces No. VIII, VII, VI).

The Ruscinian-Csarnotian Stages were followed by the so called Late Villafranchian (Villanyian) Stage (3.0–1.8 Ma BP), the fauna and climatic conditions of which suggest similar ecological conditions to those of the Bérbaltavarian Stage (KRETZOI, M. 1983; KORDOS, L. 1991, 1992). The disappearance of the subtropical fauna of the warm and humid Csarnotian Stage and the quick intrusion of the heat and dry tolerant steppe fauna refers to the dominance of continental climate with little precipitation.

During Villanyian Stage lasting for 1.2 million years, fluvial erosion was not significant because of lack of water. Fluvial terraces did not evolve, only debris cones, “meridionalis pebbles” (Kisláng), wide and shallow wadis developed owing to the low amount of seasonal precipitation.

In the Gerecse Hills fluvial gravels cannot be detected in the substrata of travertine (the lower pediment) situated, according to PÉCSI, on the terraces No. VI–VII. at 200–220 m a.s.l. and 230–240 m a.s.l. due to the warm and dry climate (Figure 5, Photo 1). The sporadic pebbles involve pebbles which eroded from upper levels and redeposited on the lower-lying Villanyian pediment, and flesh-colored, varnish coated, sporadic pebbles which redeposited in the tetarata basin containing the Kisláng fauna.

The paleomagnetic analyses confirmed that the travertine covering the Danube terrace No. V. at 180 m a.s.l. and the underlying terrace material had been developed at the beginning of Matuyama paleomagnetic era and during the Jaramillo geomagnetic events. The relative chronological age of the fossil fauna found in travertine deposits also reinforced the results above (JÁNOSSY, D. 1979; SCHEUER, GY. and SCHWEITZER, F. 1988) (Figure 6).

The Mediterranean Sea started to cool about 2.0–2.2 million years ago (FUNDER, S. *et al.* 1985).

The most obvious first sign of global climate cooling was the appearance of North Sea fauna species in the Mediterranean Sea. The cooling was enhanced by the ice sheet becoming permanent and ever growing around the

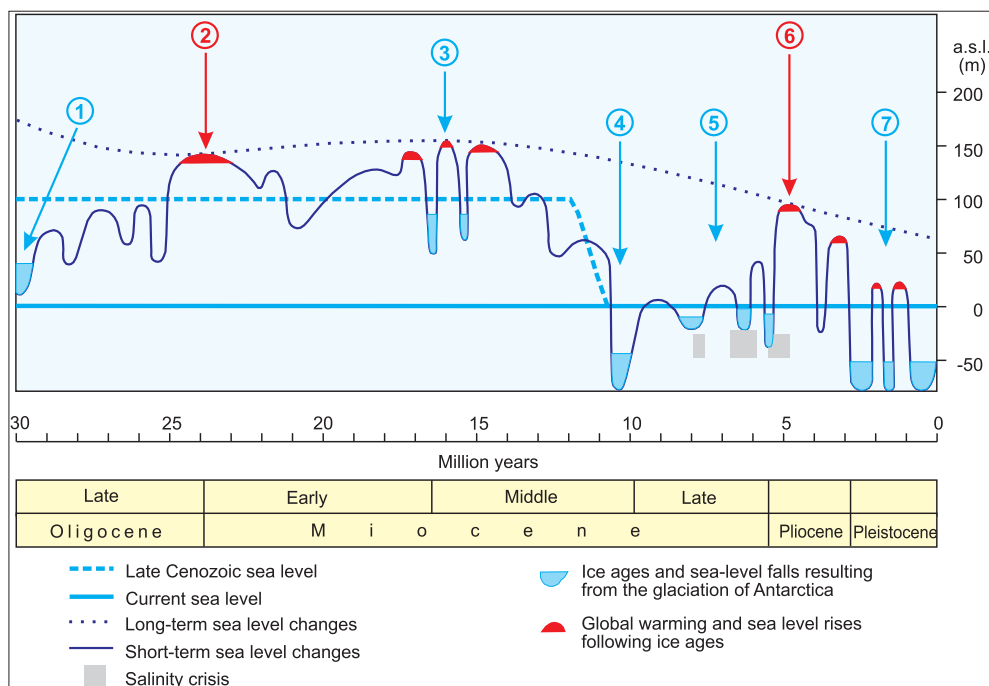


Fig. 3. The possibility of ice ages in the Late Cenozoic (eustatic sea-level changes by SCHWEITZER, F. 2004, based on HAQ, B.U. *et al.* 1987). – 1 = The Antarctica floated to the South Pole and it started to glaciare (32–30 million Ma BP); 2 = According to HAQ, B.U. *et al.* (1987) the average global temperature rose by 3–6 °C; 3 = During the Badenian Stage (17.2 Ma BP, by STEINIGER, F.F. 1999) a significant marine regression and the further glaciation of the Antarctica were likely to take place. Thanks to the continental link between Eurasia and America, *Anchitherium* species (pre-historic horse) migrated into Eurasia from Alaska and after the withdrawal of the Paratethys, *Miomastodon-Zigolophodon* species (mastodon) moved from Africa to Europe; 4 = Further probable glaciation of the Antarctica during the Sarmatian Stage; *Hipparion* invasion from North America across the Bering Strait due to marine regression (“*Hipparion Datum*”); 5 = Miocene/Pliocene boundary; shifting from brackish-water sedimentation (*Congeria*) to freshwater sedimentation (*Unio*); Lake Pannon was accumulated and it dried up; the re-glaciation of the Antarctica (7–6 Ma BP) referring to global climate change, e.g. the desertification of North China (6.2–5 million Ma BP); 6 = During the Csarnotian-Ruscinian Stages (4.4–3 Ma BP) the Antarctic and the Greenland ice sheets completely melted; the coastal water temperature rose by 8–10 °C; the global sea level was 80–100 m higher than today; 7 = Pleistocene glaciations; the global sea level decreased again; a continental link was re-exposed between North America and Eurasia (2.5–0.01 Ma BP); the development of terrestrial ice sheets (“*Equus Datum*”)

North Pole. The climax of the process started 1.0–1.2 million years ago (ZUBAKOV, V.A. and BORZENKOVA, I.I. 1990) also representing the boundary between the Upper and Lower Biharian stages introduced by KRETZOI and the starting point of a significant climate cooling in the Carpathian Basin resulting in the development of further Danube terraces (terrace No. IV. /350,000 Th-U years/, No. III.

/190,000 Th-U years/, No. II/b /120–90,000 Th-U years/, No. II/a /30–12,000 C<sup>14</sup> years/, No. I. /11,000 C<sup>14</sup> years /). In 2006 GÁBRIS, Gy. among others, make an attempt to give a new explanation for the evolution and the chronological order of the Hungarian fluvial terraces, including, of course, the Danube terraces for the period starting with the Jaramillo subchron.

European marine biochronology		Terrestrial /mammal/ biochronologies										
Mediterr.	Paratethys	European				Chinese	North American	MY				
		Subepoch	Age	Subage	MN/Q ind.	Ages	Ages					
Tyrrhenian		Danubian	European	Toringian	19	Choukoutien	Rancholabn	1				
Monastirian				Biharian	18		Nihewanian	Irvingtonian	2			
Sicilian				Villányian	17	Youhean	Blancan	3				
Emilian				Villafranchian	16	Jinglean						
Calabrian				Ruscinian	14							
Piacenzian	Pannonian	Catalonian	Barótián	Csarnótián	15	Baodean	Hemphillian	4				
Zanclean				Ruscinian	14			5				
Messinian				Bérbaltavárián	13			6				
Tortonian			Baltavarian /=Turolian	Eppelsheimian /=Vallesian	Hatvanian			12	Bahean	Clarendonian	7	
					Sümeгийн			11				8
					Csákvárián			10				9
					Rhenohassian							
Serravallian			Sarmatian	Astaracian	Bodvaian			9	Tunggurian	Barstovian	10	
					Hipparion-datum			8				11
					Monacian			8				12
Langhian	Badenian	Orléanien	Grivian	7	?	Hemingfordian	13					
			Sansanian	6				14				
Burdigalian	Eggenburgian	Aragonian	Pontilevian	5	Shanwangian	?	Africarean	15				
			Collongian	4					16			
			Romieviaian	3b					17			
			Tuchoricean	3a					18			
Aquitanian	Egerian		Laugnacian	2b	Xiejian			19				
			Cerandian	2a					20			
Chatthian			Paulhiacian	1				21				

Fig. 4. Late Cenozoic biostratigraphic correlation between Asia and Europe (based on the works of KRETZOI, M.)

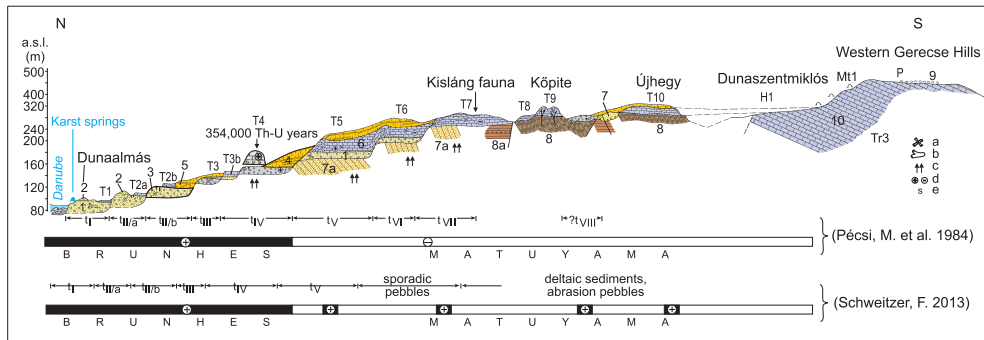


Fig. 5. Geomorphologic levels of Western Gerecse Hills along the section between Dunaalmás and Dunaszentmiklós. Based on figure by PÉCSI, M. *et al.* 1985 (re-edited by SCHWEITZER, F. 2013) – 1 = Fluvial terrace gravels and sand. The gravels of the presumed terrace No. VIII (numbered by PÉCSI, M.) deposited on the Upper Pannonian deltaic gravels by eroding the Upper Pannonian sandy deposits consisting of sand and pea gravels represent erosive discordance; 2 = Quicksand; 3 = Remnants of Pleistocene cryoturbation; 4 = Loess, slope loess; 5 = Fossil soils in loess; 6 = Travertine levels (T1–T10); 7 = Upper Pannonian cross-bedded sand (?), Bértalvarian Stage; 8 = Upper Pannonian clay; 9 = Miocene terrestrial gravels; 10 = Late Triassic limestone; H1 = Remnants of Late Pliocene pediment; at the edge of the pediment. The Upper Pannonian abrasion terrace No. 2 is superimposed; Mt1 = Upper Pannonian abrasion terrace; P = Pre-Tertiary and Tertiary planation surface with Miocene terrestrial gravel patches (?); a = fauna site; b = carbonized tree trunk remnant; c = funnel-shaped traces in travertine and gravels created by thermal spas; d = paleomagnetic polarity; e = sporadic gravels on the lower-lying pediments



Photo 1. The Kisláng fauna having developed during the Olduvai event was embedded in travertine at Dunaalmás) – 1 = Old loess deposited during Olduvai geomagnetic polarity event; 2 = Kisláng fauna site; 3 = Travertine layers (Photo by SCHWEITZER, F.)



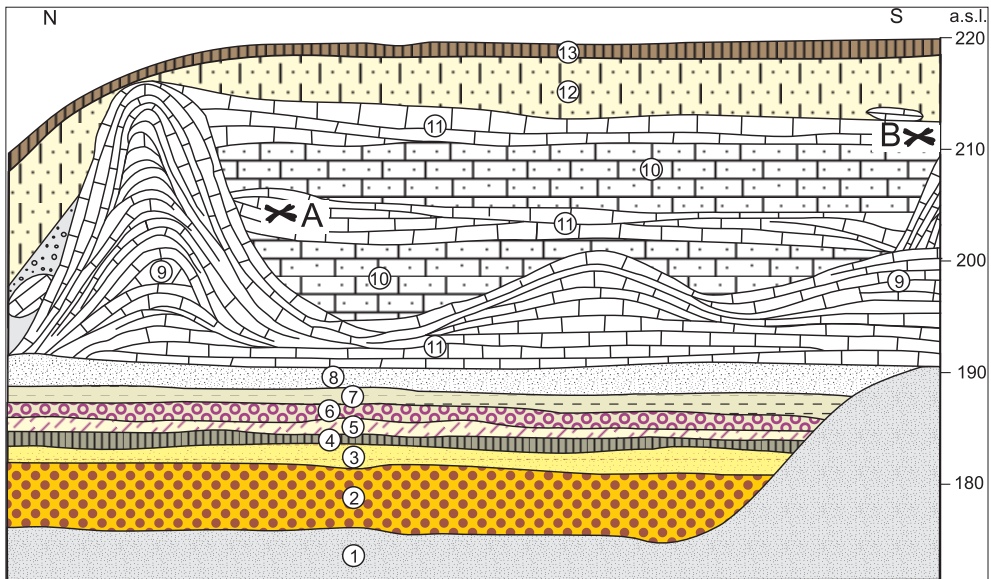


Fig. 6. Travertine level No. V, the exposure of a tetarata basin. The travertine deposited on the Danube terrace No. V. (by SCHWEITZER, F.) – 1 = Upper Pannonian yellow medium sand; 2 = sandy gravels deposited on Danube terrace No. V.; 3 = sand with gravel; 4 = sand; 5 = light yellow clay with embedded travertine and quartz pebbles and travertine layers of 1–5 cm width; 6 = yellowish grey silt with embedded travertine and quartz pebbles; 7 = yellowish grey calcareous, sandy silt; 8 = calcareous sand; 9 = tetarata dams; 10 = fluvial sand, calcareous silt; 11 = travertine bed; 12 = sandy loess; 13 = recent soil; A = *Clemmys méhelyi* Kormos (= *Emys orbicularis* L.), *Megaloceros* sp.; B = *Archidiskodon meridionaris* (*planifrons*) finding, reversed polarity (Jaramillo?)

## The ancient Visegrád Gorge

### *The ancient Danube in the Late Miocene*

The Pannonian Sea (later only a lake) having been the last sea in the Carpathian Basin was withdrawing rapidly and it was completely accumulated (Figure 7). As a result of the Pannonian transgression, thick layers of pebbles (Hollabrunn-Mistelbach Formation) originating from the deltaic sediments of rivers flowing into the Pannonian Sea were deposited NEE of Krems (SCHLESINGER, G. 1912; FINK, J. 1961, 1967; THENIUS, E. 1978). The gravel deposits can be found from the Vienna Basin along the northern edge of the Dunazug Hills as far as the Pest Plain (Mogyoród).

The geomorphological situation of gravel deposits in the Vienna Basin is similar to that

of abrasion pebbles, deltaic gravels and travertine (Új Hill, Süttő Hill /*Tapirus Arvernensis*, *Anancus Arvernensis*, *Archidiskodon Meridionalis*/, Kőpíte Hill /*Anancus Arvernensis*/, Muzsla Hill /*Derissena Auricularis*/, Poc-kő Hill) situated at 300–330 m a.s.l. in Gerecse Hills and deltaic gravels in Mogyoród cemented with travertine containing the fossils of *Hipparion*, *Melanopsis aquensis* GRAT, *Viviparius sadleri* PARTSCH, *Bithinia proxima* FUSCH and covered with bentonite deposits of 1–2 m width in some places (SCHEUER, Gy. and SCHWEITZER, F. 1984; SCHWEITZER, F. 1993) (Photos 2–6).

Presumably, the deltaic gravels were not deposited by the ancient Danube but during the accumulation of Paratethys. There were probably flat or low-situated piedmont plains formed and dissected by the anabranching consequent streams of the

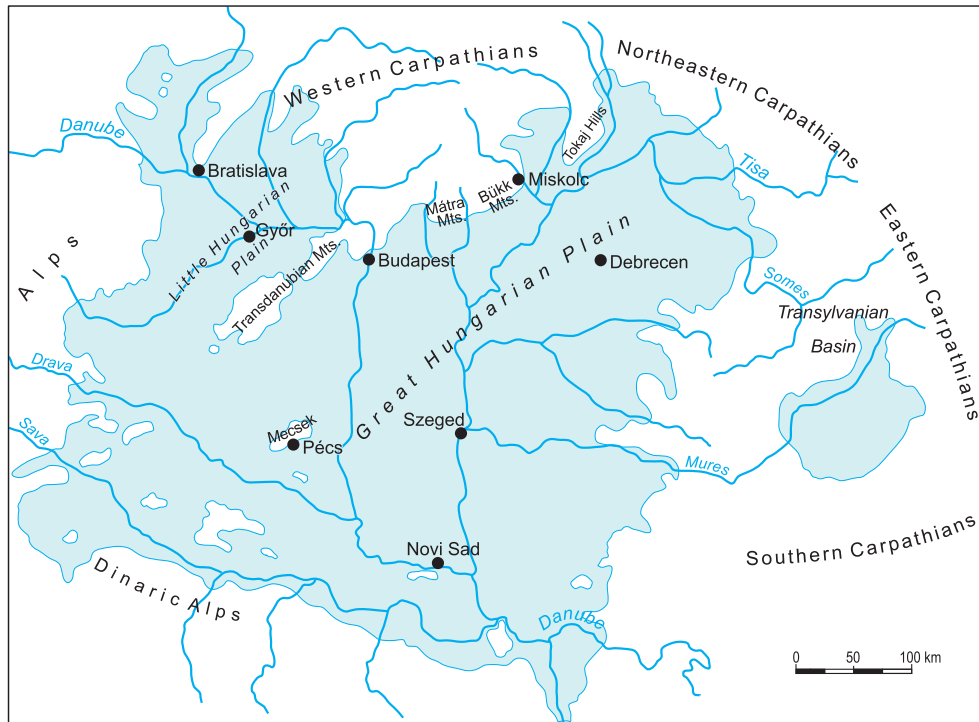


Fig. 7. The greatest extension of Lake Pannon in the Carpathian Basin (by JÁMBOR, Á. *et al.* 1987)

Alps and the Northern Carpathians which deposited deltaic gravels of several meters width (*Photo 7*).

Besides the Vienna Basin (PAPP, A. 1950), gravel deposits can be found at the NNE margin of the Pest Plain, at the northern rim of the Gerecse Hills at Dunaalmás, Süttő, Lábatlan, etc. The deltaic gravel layers deposited at the former base level of erosion are covered or dissected by Upper Pannonian travertine deposits at Öreg Hill in Dunaalmás (330 m a.s.l.), in Dunaszentmiklós (325 m a.s.l.), in Alsóvadács (335 m a.s.l.) or in the Vienna Basin at 360 m a.s.l. and below, for example at Trautmannsdorf where deltaic gravels deposited over *Congeria neum* layers.

Simultaneously, with the basaltic volcanism as old as 7–8 million years, the ridge of the Transdanubian Mountains – Gleichenberg Ridge was raised. As a result of that, Rába changed its direction to the NE, the Danube

and its tributaries changed their directions to the E, flowing along the northern edge of the Gerecse Hills, all together towards the “Visegrád Gorge” which presumably existed 12–13 million years ago. Later, the Danube broke through the strait towards the Hungarian Great Plain and flooded the lowlands (SALAMON, F. 1878; PÉCSI, M. 1985). There are two evidences for the existence of the strait: the remnants of geysers evolved on the geomorphological surface situated at the height of 260–270 m a.s.l., in the vicinity of Szokolya and Magyarkút, and the quartz pebbles located on the right rim of the Szokolya Basin at the height of 310–350 m a.s.l., E-SE of Királyrét. Increasing the distance from Szokolya-Királyrét in the direction of Vác, South of Kismaros, the pebble deposits are getting thinner (*Figure 8*).

A great interfluvial ridge seems to have evolved between Visegrád and Verőce cre-



Photo 2. Deltaic deposit on Upper Pannonian loamy sand at 298 m a.s.l. on the eastern side of Kópité Hill, South of Dunaalmás (Photo by SCHWEITZER, F.)

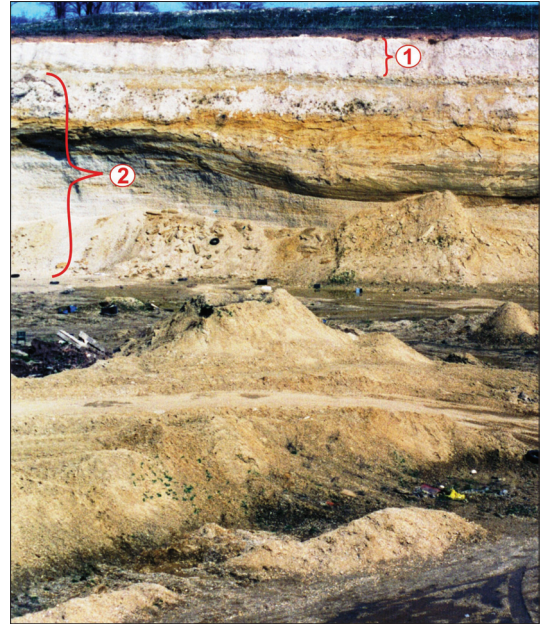


Photo 3. Deltaic deposit (2) covered with thick bentonite layers (1) in the old gravel mine in Kerepestarcsa (Photo by SCHWEITZER, F.)



Photo 4. Deltaic gravel deposit with *Hipparion* fauna cemented with travertine (298 m a.s.l.) (Photo by SCHWEITZER, F.)



*Photo 5.* Remnants of geyser cones in Magyarkút at 230 m a.s.l. Their evolution is related to post-volcanic activities of andesitic volcanism (Photo by SZEBERÉNYI, J.)



*Photo 6.* Gravel deposit of 2–3 m thickness made up of mainly rolled quartz pebbles in Királyrét-Nógrád (Photo by SZEBERÉNYI, J.)



Photo 7. Large, rolled, dreikanter-like quartz boulder of 50–60 cm diameter at 290–300 m a.s.l. (Photo by SZEBERÉNYI, J.)

ating a natural barrier hindering the southward opening of “Visegrád Gorge”. Thus, thinking of the strait as a link towards Nógrád through the Szokolya Basin is only a hypothesis (Figure 9, Photo 8).

The interfluvial ridge between Visegrád and Verőce was also formed by headward erosion as it was previously referred to by KÁDÁR, L. (1955) as well. Furthermore, it is remarkable that sporadically occurring pebbles and strath terraces can be observed on the geomorphological surfaces of the Danube Bend at the height of 230–330 m a.s.l. (the northern rim of Gerecse Hills) and at the height of 350–370 m a.s.l. between Dunaalmás and Nagymaros-Visegrád, however, the pebble deposits are completely missing and only young terraces evolved below the height of 180–200 m a.s.l., along the section of Verőce–Dunabogdány–Budapest. The latter ones, nevertheless, can be detected on both sides of the Danube between Dunaalmás and Budafok and they

can also be detected in the cores sampled in the Great Hungarian Plain (Noszky, J. 1933; LÁNG, S. 1953; KÉZ, A. 1956; PÉCSI, M. 1959; RÓNAI, A. 1972) (Figure 9).

There are further evidences for the existence of the ancient “Visegrád Gorge” in Zebegény at the height of 180–190 m a.s.l. where the patches of coarse sand deposited on andesite in several places are good examples for the fact that the shallow coral bays which evolved during the Badenien Stage (13–14 Ma BP) later were covered and temporarily buried either by fluvial sand or under arid, semi-arid climate by fluvial and eolic sand, namely, in the Sarmatian Stage (12–13 Ma BP) and in the upper stages of Late Miocene (7–5 Ma BP).

That’s how the ancient Danube and its tributaries having filled up with sediments the the system of shallow lakes which became brackish and later fresh water lakes during the Late Miocene.

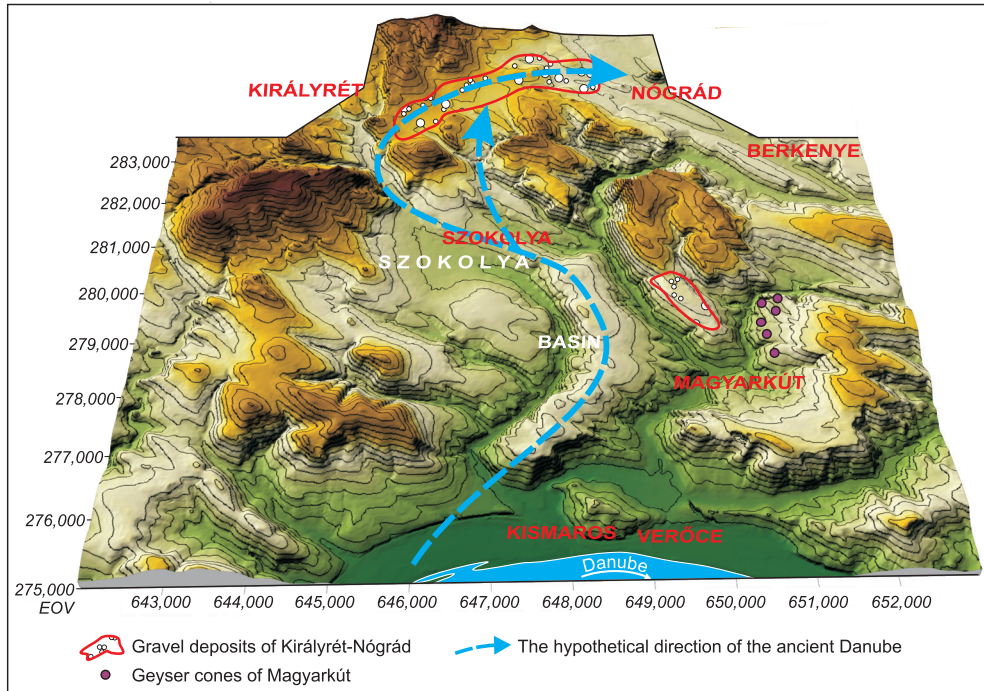


Fig. 8. Locations of gravel deposits of Királyrét-Nógrád, the geysers cones of Magyarkút in the vicinity of Szokolya Basin (based on SCHWEITZER's hypothesis)

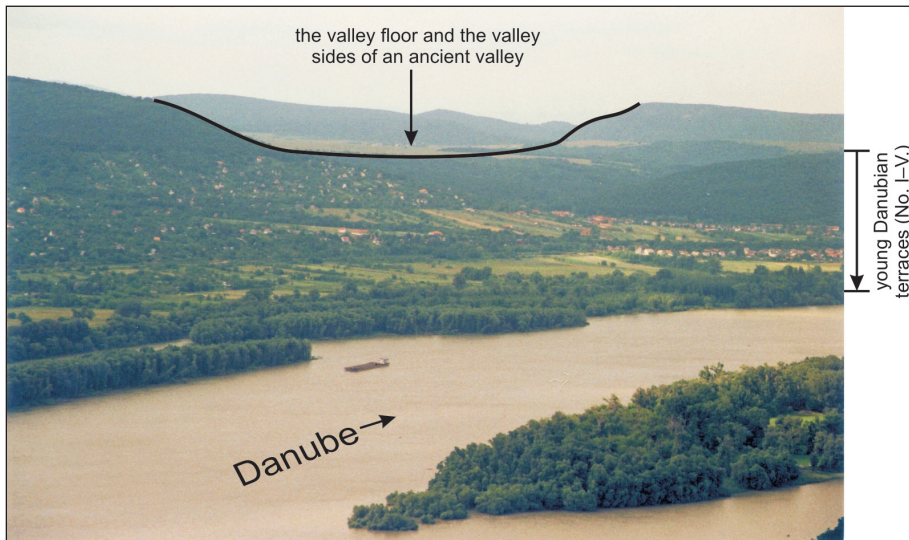


Photo 8. Ancient erosional valley between Nagymaros and Verőce (240–250 m a.s.l.) and 140–150 m relative height above the Danube. It can be followed all along the Morgó Stream in the direction of Szokolya-Királyrét. On the left and right side of the photo the younger Danube terraces can be seen at 180 m a.s.l. and below (Photo by SCHWEITZER, F.)

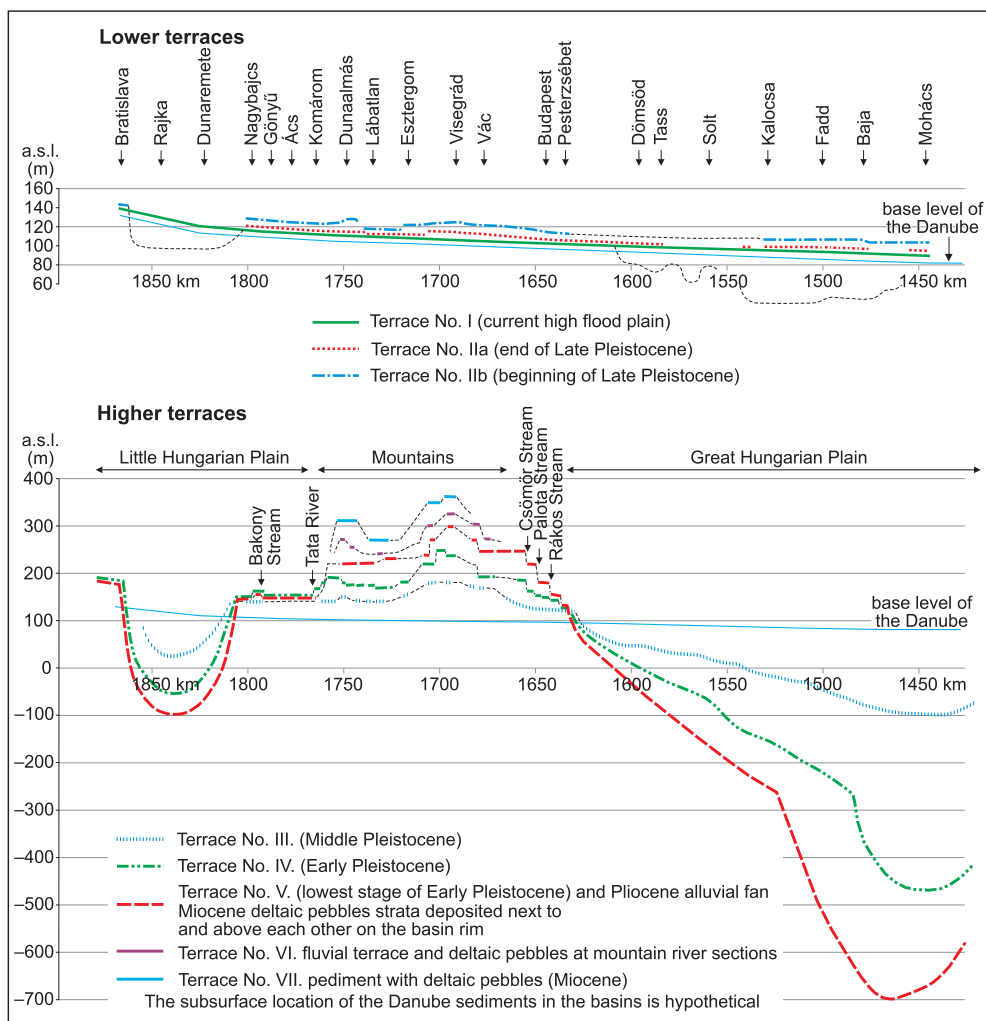


Fig. 9. The locations of Danube terraces along the Hungarian section of the Danube (based on the works of Pécsi, M.)

### Drainage system development in the Carpathian Basin

At the end of the Late Miocene Sub-Epoch (7–8 Ma BP) and at the beginning of Pliocene Epoch significant changes took place in the Carpathian Basin. As a result of a dynamic global climate change, the previous warm and humid subtropical climate turned into drier, warmer and more extreme resulting in the dramatic shrinkage, gradual accumula-

tion and dry-up of Lake Pannon. The climax of that period was the so called Béraltavári-an Stage (KRETZOI, M. 1969; KORDOS, L. 1991, 1992; KRETZOI, M. and PÉCSI, M. 1979) which is equivalent to the Messinian salinity crisis considering the international nomenclature of geological timescale (SCHWEITZER, F. 1993, 2004). The fauna findings (birds *Meriones*/, *Giraffidae*, *Hipparion* and *Anthilope* species) of the Carpathian Basin (KORMOS, T. 1911; KRETZOI, M. 1962; KORDOS, L. 1992) (Figure 10) and

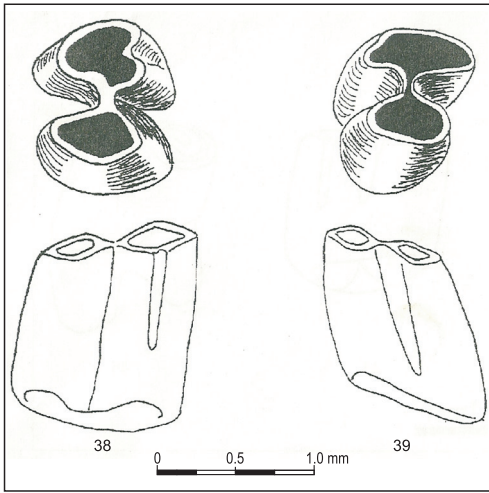


Fig. 10. *Epimeriones (gerbils) molars* found in cross-bedded sand in Egyházasdengeleg (by HIR, J. and MÉSZÁROS, L.Gy. 1995)

its environment provide an evidence for the hot and dry semi-arid climate evolved as a consequence of global climate change.

During the Bérbaltavarian stage a hot and dry semi-arid climate evolved in the Carpathian Basin where large sand dunes

and torrents with riparian forests appeared (MOTTL, M. 1941). Arid and semi-arid areas characterized by sedimentary rock formations with limestone, dolomite and gypsum were dominant in the basin (SCHWEITZER, F. 1993; SCHWEITZER, F. and SZÖÖR, Gy. 1997). Under the hot and dry climate the fragmentation of rocks resulted in the accumulation of huge amount of sand deposited over the mudrocks of Lake Pannon in varying thickness (50–200 m). The investigations pointed out that the torrents crossing the Little Hungarian Plain had been flowing southwards in the direction of Slavonic Basin, then they accumulated the whole Little Hungarian Plain (SZÁDECZKY-KARDOSS, E. 1939; SÜMEGHY, J. 1953). The siliceous crust is an evidence for the arid climate characterized by an annual mean precipitation of only 150–250 mm conducive to the evolution of torrents but not to that of fluvial terraces (SCHWEITZER, F. and SZÖÖR, Gy. 1997).

During the Lower Pannonian Stage (Eppelsheimium in the Hungarian terminology) the tropic rainforests which previously had covered even regions at higher latitudes contracted to a smaller area around

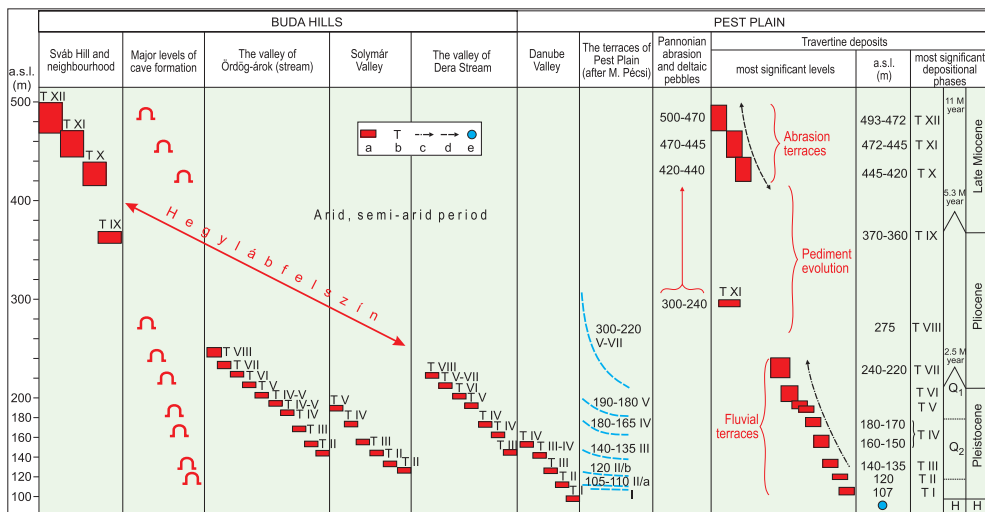


Fig. 11. The evolution and the development of drainage network in the Carpathian Basin based on travertine stratigraphy (by SCHWEITZER, F. 1993–2013). – a = travertine levels (by SCHEUER, Gy. and SCHWEITZER, F. 1984); b = the most important levels of travertine deposition; c = travertine deposition on valley sides; d = the tectonic elevation of János Hill and Sváb Hill; e = the level of resurgence of recent karst springs



the Equator due to the global climate change. Then under the warm and humid climate of the Late Pliocene (Csarnotian Stage, 4–3 Ma BP) favouring red clay development, tropic rainforests expanded again. The development of the drainage system of the Danube and the whole Carpathian Basin lasting until the present time (KRETZOI, M. and PÉCSI, M. 1979; SCHEUER, GY. and SCHWEITZER, F. 1988; SCHWEITZER, F. 1993) (Figure 11) also started and the rivers dissected the pediments which evolved during the warm and dry period of Béraltavarian (Messinian) Stage.

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